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THE METEOROLOGICAL MAGAZINE

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WIND SPEEDS OVER SHORT PERIODS OF TIME

By C. S. DURST, O.B.E., B.A.

With the use of lighter and lighter materials in building construction, engineers are being forced to consider the wind structure in greater detail and its effect on the individual members of their buildings. Indeed the engineering of modern buildings is involving aerodynamics in a manner undreamed of till lately. In particular, since the aerodynamic pressure on a plate is proportional to the square of the velocity of the wind passing over it, economy demands that the probable maximum speed of the wind affecting any member of a building should be assessed with some accuracy. Moreover the duration of the passage of a high-speed parcel of air is intimately associated in its pressure effect with the dimensions of the member on which it is operating; hence it is a matter of considerable interest to engineers to know the wind speeds which are likely to operate over short time-intervals. The published records are mainly hourly mean values and maximum gusts: the former is far too long an interval for the engineers' requirements; the latter, if made by a Dines pressure tube anemograph, refers probably to an interval of two to three seconds; with the new electrical cup anemograph the maximum gust will refer to a still shorter interval. However, between two seconds and 60 minutes there is a gamut of intervals which are uncatered for except by the research work done with open-scale Dines recorders, as at Cardington,¹ and pressure plates, as at Ann Arbor, Michigan^{2, 3} and the very fine-scale work done by Scrase.⁴

In what follows an attempt is made to use the data of these researches to make a statistical assessment of the wind speeds likely to occur in shorter intervals of time when the mean hourly wind speed falls in certain ranges.

To do this we suppose that the wind F at any time t can be represented by

$$F = V + v + x,$$

where V is the mean wind over, say, the hour, $V + v$ is the mean wind over, say, the 10 min interval and $V + v + x$ is the mean wind over the particular short period (perhaps 5 sec) in which we are interested.

Thus $[F]_{600} = V + v$ and $[F]_{3600} = V$,

where square brackets denote mean values averaged over intervals of 10 and 60 minutes respectively.

Moreover the mean square of F is

$$[F^2]_{3600} = [V^2] + [v^2] + [v^2].$$

Hence we can look on the mean square of the velocity as being made up of the mean square of the hourly wind, plus the mean squares of the departures of the 10 min means from the hourly means, plus the mean squares of the departures of the 5 sec mean winds from the 10 min means.

Moreover if the frequencies of the short-period means follow the normal Gaussian distribution, it is possible from tables of frequencies such as those quoted by Brooks and Carruthers³ to estimate the maximum gust over a given short period likely to occur during an hour when the mean wind is of a given speed.

The distribution of the short-period winds about the 10 min means was examined in the data for Cardington given in *The structure of wind over level country*.¹ The frequencies of speed, during 5 sec periods, from the "ultra quick runs" were plotted on probability paper for a number of the records and in only one case was there a marked divergence from the Gaussian frequency; that was the case of the "ultra quick run 361" in which at one anemometer the wind speed rose from 43 m.p.h. to 69 m.p.h. in 5 sec and remained between 66 and 73 m.p.h. for 20 sec before it dropped back to 46 m.p.h. The three other anemometers of the layout, which were within 700 feet of this one and were in operation at the same time, showed nothing of this surge of high air speed. Apart from this surge no 5 sec speed at any of the four anemometers was greater than 54 m.p.h.

Provided the possibility of such rare occurrences is borne in mind it is legitimate to assume that winds follow closely a Gaussian distribution.

If we consider an anemogram in which there is no general change of wind direction or speed during the period T and if we measure the values of the wind in each small interval of time t , we then have a number T/t of wind measurements from which we can form a frequency distribution, or we can take a mean value M of the wind over the period T and derive the departures from the mean of the wind measured over each interval t . If we call these departures $m(Tt)$ we can derive the standard deviation $\sigma(Tt)$ where

$$\sigma(Tt) = \sqrt{\frac{\sum \{m(Tt)\}^2}{(T/t) - 1}},$$

which is so written to imply that the standard deviation is of winds measured over the short interval t about the mean measured over the period T . Similarly $M(T)$ indicates the mean over time T .

In *The structure of wind over level country*¹ there are set out the values of wind speed over 5 sec intervals during periods of about 10 min. Occasions were chosen when there were no obvious general changes in wind direction or speed and calculations were made from seven occasions of the mean wind speed over 10 min and the standard deviations of mean winds averaged over 5, 10, 15, 20, 25, 30, 40, 50 and 60 sec. These standard deviations are set out in Table I.

When the values of the standard deviations for the 5 sec means in Table I are plotted against the mean speed it is seen that they are nearly proportional, with a ratio of about 0.145, whereas the ratio of the standard deviations for

TABLE I—MEAN SPEED M (10 MIN) AND STANDARD DEVIATION σ (10 MIN, t) FOR SEVEN CASES OF 10 MIN RECORDS

Run no.	Mean speed	Period t in seconds								
		5	10	15	20	25	30	40	50	60
314	22.9	3.5	3.3	3.2	3.0	2.9	2.7	2.7	2.5	2.2
361	41.2	7.6	7.0	6.7	6.6	6.9	6.3	5.1	5.5	5.0
401	11.3	1.4	1.3	1.3	1.2	1.2	1.1	1.1	0.9	0.9
391	34.3	4.5	4.1	4.0	3.7	3.6	3.4	3.1	2.8	2.8
393	27.2	4.4	3.9	3.7	3.7	3.4	3.4	3.3	3.2	3.1
97	42.1	5.1	4.7	4.4	4.0	4.0	3.8	3.5	3.1	3.2
147	12.1	1.7	1.6	1.5	1.5	1.4	1.4	1.2	1.1	1.1

60 sec means to M (10 min) is about 0.095. Indeed on average the ratios of these standard deviations to the mean 10 min winds are as follows in Table II.

TABLE II—AVERAGE RATIO OF STANDARD DEVIATION OF SHORT-PERIOD MEANS TO MEAN VALUE OF WIND OVER 10 MINUTES (SEVEN CASES)

Period in seconds (t)	5	10	15	20	25	30	40	50	60
Ratio $\frac{\sigma(10 \text{ min}, t)}{M(10 \text{ min})}$	0.145	0.135	0.128	0.124	0.120	0.115	0.107	0.098	0.095

To confirm how closely the standard deviation is related to the mean wind a further nine cases were calculated of the standard deviation of 5 sec mean winds about the 10 min means. The sixteen cases are shown in Table III.

TABLE III—10 MIN MEAN WINDS AND STANDARD DEVIATIONS OF 5 SEC MEAN WINDS ABOUT THE 10 MIN MEAN WINDS

Run no.	Wind speed over 10 min $M(10 \text{ min})$ m.p.h.	Standard deviation of 5 sec mean wind speeds $\sigma(10 \text{ min}, 5 \text{ sec})$ m.p.h.	Run no.	Wind speed over 10 min $M(10 \text{ min})$ m.p.h.	Standard deviation of 5 sec mean wind speeds $\sigma(10 \text{ min}, 5 \text{ sec})$ m.p.h.
97	42	5.1	371	28	2.0
147	12	1.7	389	31	3.5
314	23	3.5	391	34	4.5
344	19	2.2	392	30	3.1
351	20	3.7	393	27	4.4
357	28	3.3	401	11	1.4
361	41	7.6	402	10	1.1
368	32	3.6	427	23	2.9

The relationship of these is shown in Figure I.

The correlation coefficient is 0.87 and the consequent regression equation is

$$\sigma(10 \text{ min}, 5 \text{ sec}) = -0.2 + 0.14 M(10 \text{ min}).$$

The standard error is 0.75 m.p.h.

To a close approximation we can say

$$\frac{\sigma(10 \text{ min}, 5 \text{ sec})}{M(10 \text{ min})} = 0.14.$$

In the seven cases where the standard deviation of 60 sec mean values had been worked out the correlation coefficient was about 0.9 and the ratio

$$\frac{\sigma(10 \text{ min}, 1 \text{ min})}{M(10 \text{ min})} = 0.10.$$

Further, as there were in existence tabulations of the Cardington 50 ft anemograms giving the mean hourly winds and also the mean wind speeds over the 10 min interval before each hour, it was possible to obtain a relationship between the mean wind over 10 min and the hourly mean. Forty-four days were

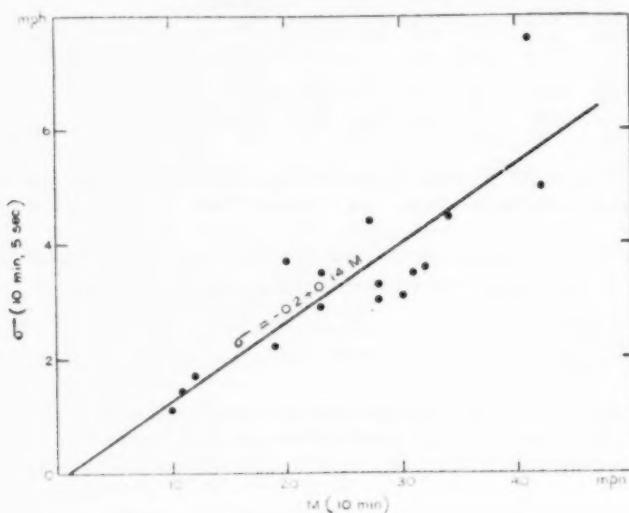


FIGURE 1—GRAPH OF $\sigma = -0.2 + 0.14 M$

picked out from the period September 1928 to May 1929 when there were no significant changes of wind in speed or direction. These 44 days were classified into three groups according to the general level of the wind speed: namely, light winds with an average of 13 m.p.h. (25 cases), moderate winds with an average of 20 m.p.h. (15 cases) and four cases of strong winds with an average of 28 m.p.h. Each speed group was arrayed as departures from the mean wind speed of the day, and then standard deviations were formed of these departures for each group. A correction was made to allow for diurnal variation of the mean wind of the group as a whole. These standard deviations were formed for both the hourly means and the 10 min means, that is, there were calculated σ (24 hr, 1 hr) and σ (24 hr, 10 min) as is shown in Table IV.

TABLE IV—MEANS AND STANDARD DEVIATIONS FOR VARIOUS TIME INTERVALS

Characteristic grouping	No. of days	Mean speed m.p.h.	σ (24 hr, 1 hr) m.p.h.	σ (24 hr, 10 min) m.p.h.	σ (1 hr, 10 min) m.p.h.
Light winds	25	13	2.20	2.35	0.82
Moderate winds	15	20	2.66	2.84	1.07
Strong winds	4	28	3.95	4.44	2.02
All winds	44	17	2.62	2.83	1.06

Values were originally taken to a further place of decimals and were then rounded off.

In this table σ (1 hr, 10 min) has been obtained from the formula

$$\{\sigma(1 \text{ hr}, 10 \text{ min})\}^2 = \{\sigma(24 \text{ hr}, 10 \text{ min})\}^2 - \{\sigma(24 \text{ hr}, 1 \text{ hr})\}^2.$$

The mean wind speeds M (10 min) and M (24 hr) are the same provided the means are made up of a sufficiently large number of randomly chosen values.

The ratios of the standard deviations to the mean wind speed are on the whole somewhat greater for light winds than for moderate and strong winds. For all winds combined the ratio $\sigma(24 \text{ hr}, 1 \text{ hr})/M$ is 0.158 and $\sigma(24 \text{ hr}, 10 \text{ min})/M$ is 0.170. $\sigma(1 \text{ hr}, 10 \text{ min})/M$ is 0.064 for all winds combined and is 0.07 for the four cases of stronger winds.

We are now in a position to make an estimate of the magnitude of winds measured over short periods of time at sites over level country. The ratio $\sigma(1 \text{ hr}, 10 \text{ min})/M$ lies somewhere between 0.055 and 0.075; the ratios of the standard deviations over shorter periods $\sigma(10 \text{ min}, t)/M$ are those given in Table II; we can combine these and expect the standard deviations about an hourly mean wind to be

$$\sqrt{\{\sigma(1 \text{ hr}, 10 \text{ min})/M\}^2 + \{\sigma(10 \text{ min}, t)/M\}^2}.$$

These are given in Table V.

TABLE V—VALUES OF $\sigma(1 \text{ hr}, t)/M$ FOR VARIOUS VALUES OF t

t	10 min	1 min	30 sec	20 sec	10 sec	5 sec
0.055	0.110	0.127	0.136	0.146	0.155	—
0.065	0.115	0.132	0.140	0.150	0.159	—
0.075	0.121	0.137	0.145	0.154	0.163	—

The difference between the three lines of this table is not great. Using the middle line we obtain in Table VI values of $\sigma(1 \text{ hr}, t)$ for various values of the mean hourly wind M .

TABLE VI—VALUES OF $\sigma(1 \text{ hr}, t)$ FOR VARIOUS VALUES OF t AND VARIOUS MEAN HOURLY WIND SPEEDS

Mean hourly wind speed	Period t						
	10 min	1 min	30 sec	20 sec	10 sec	5 sec	$\frac{1}{2}$ sec
20	1.3	2.3	2.6	2.8	3.0	3.2	—
30	2.1	3.5	4.0	4.3	4.5	4.8	—
40	2.6	4.6	5.3	5.6	6.0	6.4	(7)
50	3.3	5.7	6.6	7.0	7.5	8.0	(9)
60	3.9	6.9	7.9	8.4	9.0	9.6	(10)
70	4.5	8.0	9.2	9.8	10.5	11.2	(11)
80	5.2	9.2	10.6	11.2	12.0	12.7	—

For shorter intervals than 5 sec, calculations made from the data of Sherlock and Stout^{2,3} show that in two sets of observations (Run 330, 340 to 384 sec and Run 330, 138 to 157 sec with four stations used in each case) the standard deviations of $\frac{1}{2}$ sec mean winds about 5 sec means, that is, $\sigma(5 \text{ sec}, \frac{1}{2} \text{ sec})$, were 3.0 m.p.h. for a mean wind of about 40 m.p.h. If such a standard deviation is added to the 5 sec means in Table V we get a value of $\sigma(1 \text{ hr}, \frac{1}{2} \text{ sec})$ of about 7 m.p.h. for a mean speed of 40 m.p.h. and probably up to $11\frac{1}{2}$ m.p.h. for a mean speed of 70 m.p.h. These figures have been added in the last column of Table VI.

Now if we assume that the distribution of, say, a 5 sec mean wind about the hourly mean is Gaussian, we can get the probable maximum gust, over that duration of time, from tables of the probability integral, for example those quoted in Appendix II of the *Handbook of statistical methods in meteorology*.⁵ Thus we can make up Table VII.

TABLE VII—FACTORS BY WHICH $\sigma(1 \text{ hr}, t)$ HAS TO BE MULTIPLIED TO PRODUCE THE MAXIMUM GUST IN ONE HOUR

t	10 min	1 min	30 sec	20 sec	10 sec	5 sec	$\frac{1}{2}$ sec
t/hr	0.167	0.017	0.0085	0.0056	0.0028	0.0014	0.00014
Factor	0.9	2.1	2.4	2.55	2.8	3.0	3.6

Finally we get estimates of the maximum gust, averaged over short periods, likely to occur once in an hour as follows in Table VIII.

TABLE VIII—PROBABLE VALUES OF THE MAXIMUM WIND SPEED, AVERAGED OVER SHORT PERIODS OF TIME t , WHEN MEAN HOURLY WIND SPEED HAS VARIOUS VALUES

Mean hourly wind speed	Period t						
	10 min	1 min	30 sec	20 sec	10 sec	5 sec	$\frac{1}{2}$ sec
20	21	25	26	27	28	30	—
30	32	37	40	41	43	44	—
40	43	50	53	54	57	59	(65)
50	53	62	66	68	71	74	(82)
60	64	74	79	81	85	89	(96)
70	74	87	92	95	99	104	(111)
80	85	99	106	109	114	118	—

If values of $\sigma(1 \text{ hr}, t)/M$ of 0.055 or 0.075 had been used instead of 0.065 the probable values of the maximum wind speed, averaged over short periods of time, would have been altered by only about one mile per hour.

It has been pointed out to me that according to Graph 4.2.2(3) of Gumbel's *Statistics of Extremes*⁶ a more appropriate value for the factor in Table VII for 10 min would be 1.2 instead of the 0.9 given by the assumption of a Gaussian distribution. This, however, makes little difference to the values of the 10 min column of Table VIII, the values up to 64 being increased by 1 m.p.h. and the two highest by 2 m.p.h.

It must, however, be noted that the figures in Table VIII strictly refer only to a site in which the wind has an unobstructed field and the topography is flat. Data do not appear to be available for any other type of exposure. However, it is believed that the values given in Table VIII can be reasonably applied to sites where the countryside is undulating but slopes are not steep. The figures must not be applied to sites where the wind arriving at the anemometer has recently travelled over obstructions such as houses or trees which are but little lower than the anemometer itself. They do not apply to winds blowing immediately off the sea on to the site.

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GRAPHICAL OUTPUT FROM COMPUTERS AND THE PRODUCTION OF NUMERICALLY FORECAST OR ANALYSED SYNOPTIC CHARTS

By J. S. SAWYER, M.A.

The problem.—When a computer is used for numerical forecasting or objective analysis the horizontal distributions of pressure, thickness, etc. are represented in the computer by the values of these quantities at a network of points forming a square grid. The forecaster making use of such a distribution of pressure or thickness normally requires it to be delineated by isopleths on a geographical chart. Thus it is customary when the results of a numerical forecast or objective analysis become available to plot the values at grid points on a chart and to draw freehand isopleths.

This procedure can become laborious and time-consuming when a number of charts are involved. For example, a recent experimental system of numerical forecasting provided 20 charts during the course of each forecast covering various times and levels, etc. Further, if an electronic computer were to become an integral part of the forecast room organization, the forecaster might willingly forego the output of some of the fields in the store of the computer, if he knew that they could be made available in graphically analysed form in a matter of seconds—he would not always be able to wait a matter of 10 or 15 minutes for the data to be plotted and analysed by hand.

With these aspects in mind a review was recently made of possible methods of graphical computer output and, although it was decided not to attach any such device to the Meteorological Office computer METEOR at present, some account of the survey may be of rather wide interest.

Methods of graphical computer output.—Possible methods of graphical output from a computer can be roughly classed as follows:

- (a) mechanical graph-plotters
- (b) use of printing devices to produce a series of points on a curve
- (c) display of graphs on a cathode ray tube.

In respect of the last category (c) it is necessary to consider the method of recording the cathode ray tube display (by photography or otherwise).

Whatever method of display is used the computer itself must be used to carry out some form of interpolation between the stored values at grid points and to determine from them the points to be plotted. The selection of all the points that need to be displayed for a typical synoptic chart on a mesh of 256×256 points requires about 30 seconds on the computer METEOR, and this time sets an upper limit to the necessary speed of the output device. (With faster computers now being built interpolation time would naturally be reduced.)

Mechanical graph-plotters.—Mechanical graph-plotters are available in which a plotting head is moved over a chart on a table and selected symbols can be plotted or straight lines drawn. These machines are normally operated by punched cards or punched paper tape, and can be fed direct from the punched output of a computer.

The plotting speed of equipment currently available in Britain is about 40 to 60 points a minute or up to 40 segments of straight lines per minute. This would represent two or three minutes for the drawing of the isopleths on one synoptic chart in addition to the time taken by the computer to punch the tape (one to two minutes). This is somewhat too slow for the purpose required.

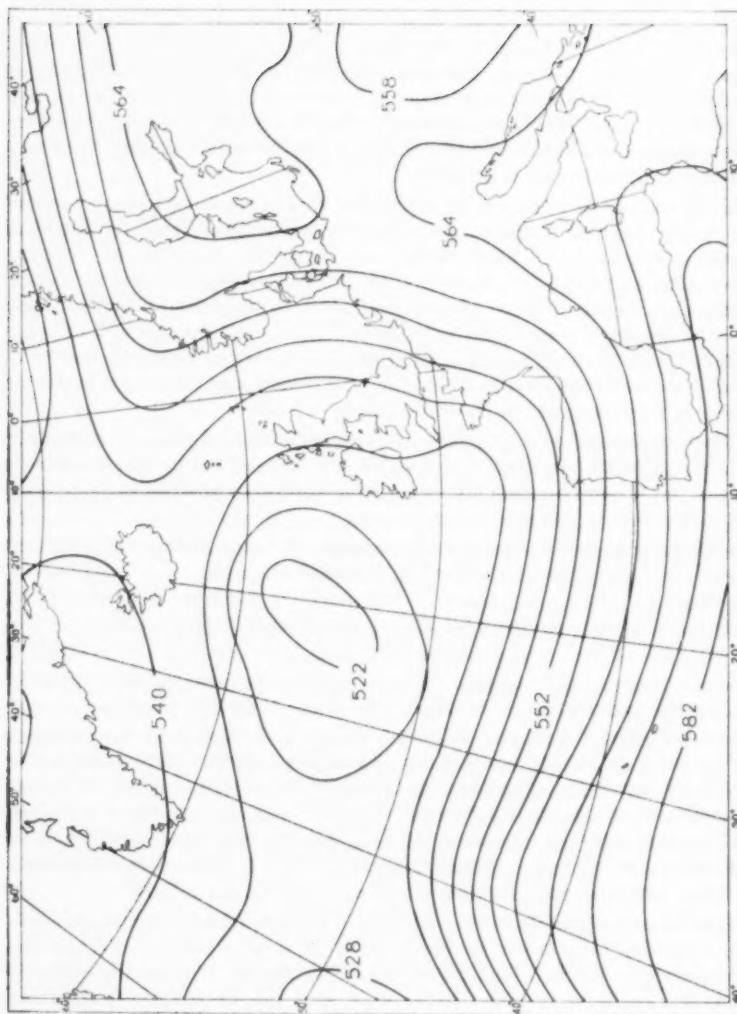


FIGURE 1—500 MB CHART FOR 0000 GMT, 16 APRIL 1959

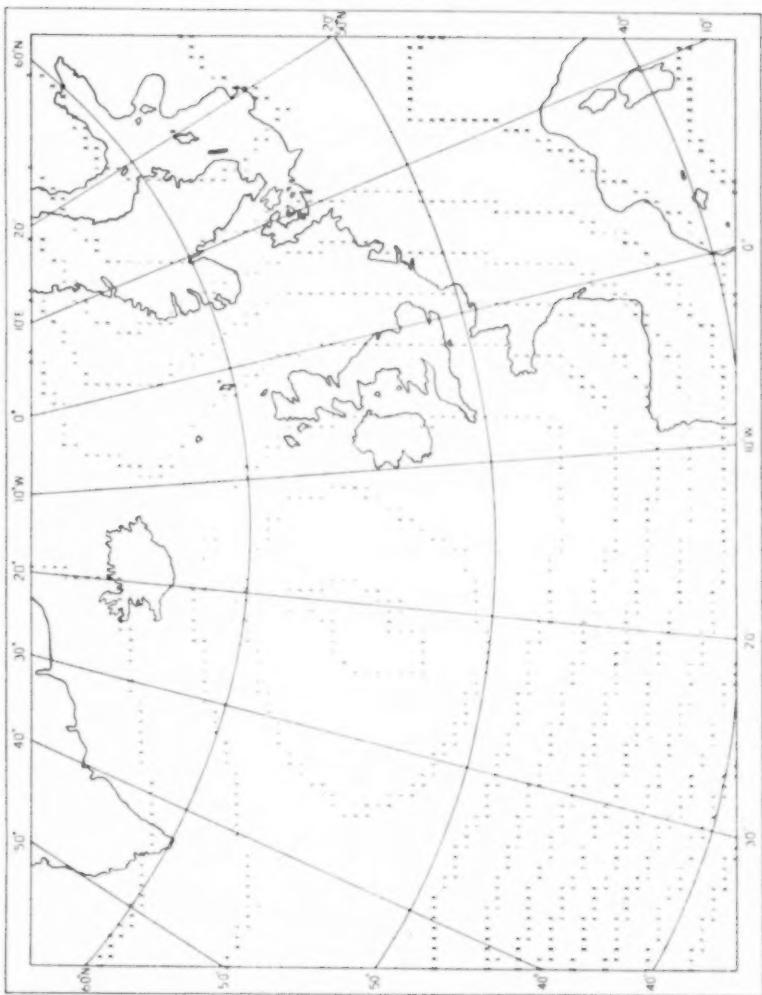


FIGURE 2.—500 MB CHART PRINTED ON THE LINE-PRINTER ATTACHED TO METEOR
The same chart drawn freehand is shown in Figure 1.

To face p. 139]

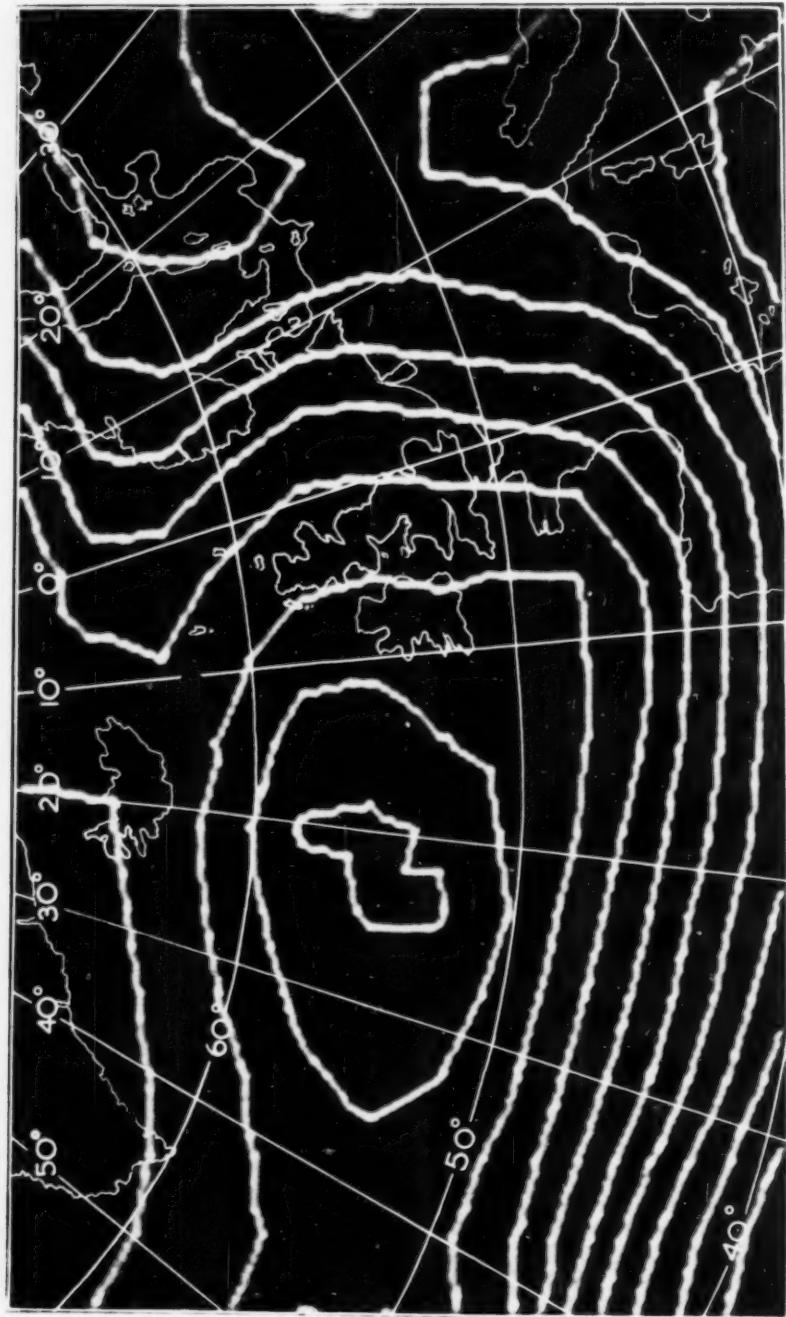


FIGURE 3.—500 MB CHART OBTAINED FROM THE CATHODE RAY TUBE DISPLAY ON THE COMPUTER AT MANCHESTER UNIVERSITY.
The same chart drawn freehand is shown in Figure 1.

Use of printing devices to produce a map.—Any page-printing device can be used to produce a map of isopleths by printing selected symbols in appropriate places on the page. A limit to the resolution is, however, imposed by the number of characters which can be printed on a line.

A teleprinter can be used in this way but the line-printer at present attached to METEOR is more suitable as it is faster and has provision for 92 characters on a line. Figure 2 is an example of a 500-millibar chart printed on the line-printer on METEOR. Interpolation and printing took about one minute. A geographical outline has subsequently been added to the chart for convenience in interpretation but in practice this could be done by superimposing a transparent overlay. The resolution on the chart is not ideal but is probably as good as is justified by the data.

The Joint Numerical Weather Prediction Unit in Washington has employed a line-printer in a similar way; in the Washington scheme the area between alternate pairs of contours is filled in with printed symbols. In Stockholm an electric typewriter attached to BESK was also used to shade in areas between adjacent contours and an example of the result is given in *Tellus*.¹

Xerographic printers which are being developed for computer output would be better suited to the printing of an isopleth map because

- (a) of their very high speed—the map could be produced as fast as the interpolation could proceed by the computer (probably about 30 seconds on METEOR)
- (b) the wide choice of characters would permit the printing of line segments
- (c) a base map could be superimposed during printing.

The disadvantage is the very high cost.

Cathode ray tube display.—An optional facility with large American computers has been the ability to display selected points on a cathode ray tube, thus illuminating a curve which can be observed or photographed. Experimental equipment of the same type (but with less resolution) was built at Manchester University and attached to the Mercury computer there.

To gain some experience of the value of the equipment for the display of synoptic charts a programme was written to produce a series of synoptic charts on the Manchester equipment. Figure 3 is an example of the result (a base map has subsequently been added.) To carry out the interpolation for all the points displayed required about 30 seconds. This is much longer than the persistence of the illumination on the cathode ray tube, and in consequence the chart could not be seen on the display. However, the camera shutter remained open while the whole pattern was covered and the complete set of isopleths was recorded.

Results of using the IBM 704 equipment in a somewhat more refined manner are reported by Wippermann² and the use of similar equipment with BESK in Stockholm is illustrated by A. Bring in a paper by Döös and Eaton.³ In both cases the time to complete the display was between a half and one minute.

These experiments all give a reasonably satisfactory synoptic chart but additional equipment for rapid photographic processing is needed, if the chart is to be available to the forecaster in a form suitable for his use within minutes. (At Manchester the films were not developed until the next day.)

The recording of the cathode ray tube display in a time acceptable for forecasting purposes presents a number of difficulties. Photography is relatively simple and inexpensive but has the disadvantage that normal processing

techniques take some 30 minutes and require enlarging for practical use. Processing can be speeded up by use of special high-speed chemicals and is relatively cheap if done manually in a dark room. Automatic equipment is available for processing and can give results in a few seconds but the cost increases very rapidly with the processing speed required.

Another suitable photographic system of rapid processing would be that in which the processing chemicals are incorporated in the film and processing is carried out in the camera, but this would require some adaption for automatic operation by the computer. A further possibility that might be explored is that of retaining the displayed synoptic chart on the cathode ray tube sufficiently long for inspection and possibly tracing by hand, thereby eliminating the need for high-speed photographic processing. However, some form of electronic buffer store would be needed to avoid holding the computer idle for long periods, and a larger display would be required than that available currently on suitable cathode ray tubes.

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THE PREPARATION OF LOCAL RAINFALL MAPS

By T. JOHNSTON and J. HOLMES

This note describes the preparation of a set of local comparative rainfall maps for the county of Ayrshire. They are intended for use by local forecasters at Prestwick dealing with public inquiries. Although they have mainly a parochial significance the method may be of use elsewhere. The possible variations in the rainfall over an area of county size (in this case about 60 by 40 miles) can be considerable on occasion. The degree of wetness of the weather can be of importance to users of forecasts, especially the building trades and the farming community. The use of the comparative charts assumes that the forecaster is most at home with his immediately local area and that his current thought includes some qualitative idea of how wet it is likely to be there.

In Ayrshire there are about fifty raingauges which are read daily at 9 a.m. The readings from these stations for 1956 were used in the preparation of the maps. In Figure 1 the topography of the area can be seen from the contours, but it can be described as a narrow low-lying coastal belt ringed by a crescent of hills which rise above 300 metres in places. Prestwick itself lies on the coast, 10 metres above sea level. The rainfall stations are fairly well distributed over the county and two areas, the hills in the north and the suburbs of Ayr, have a high concentration.

At times this close network showed very small-scale variations within the broader pattern, but on most occasions they were nearly homogeneous. Most of the raingauge readings are made only once daily, at 9 a.m. This defined the period in which a map could be prepared as 9 a.m. to 9 a.m. and limited the number of occasions which could be used. In this time the synoptic situation had not to give mixed types of precipitation (for example, cold frontal rain followed by showers). When frontal rain occurred it had to do so over the whole

of the county within the time period. We were able to use occasions of developing wave depressions passing across the area, as Sawyer¹ has shown that the rainfall fifty miles either side of the centre is nearly constant. Had a larger area been considered this would not have been possible. We ignored any periphery passage of a centre of this type for the same reason. Systems which gave only small amounts of rain were not used in the final set of maps, but some were looked at in the course of the work. The first selection of occasions was made from the *Daily Weather Report* and these were then checked against the larger-scale local working charts.

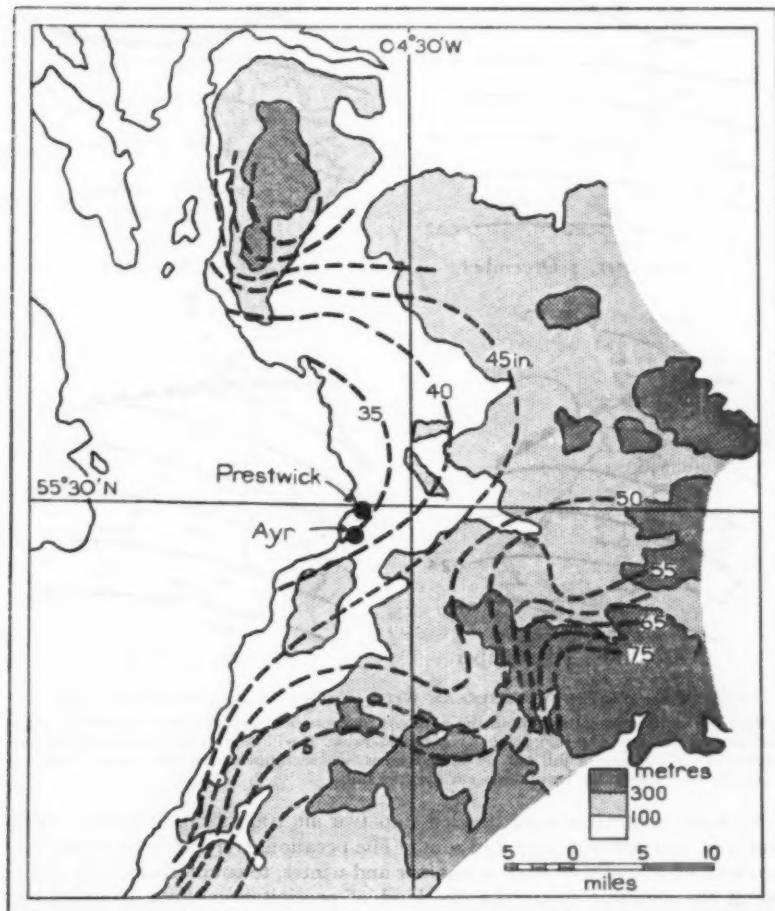


FIGURE 1—AVERAGE RAINFALL MAP OF AYRSHIRE

If one might invent a term "raininess", the maps are an attempt to present this conception in a comparative form. The rainfall at Prestwick Airport on each occasion was written at the top of the chart and was taken as unity and the

amounts at all other stations were calculated as ratios to this value; (we used no period when there was no rain at Prestwick, except in showery airstreams). They were then plotted on a chart and isopleths of the values drawn. The coverage was such that the subjective element in the drawing seems to be small. Two people working together can check on this to some extent.

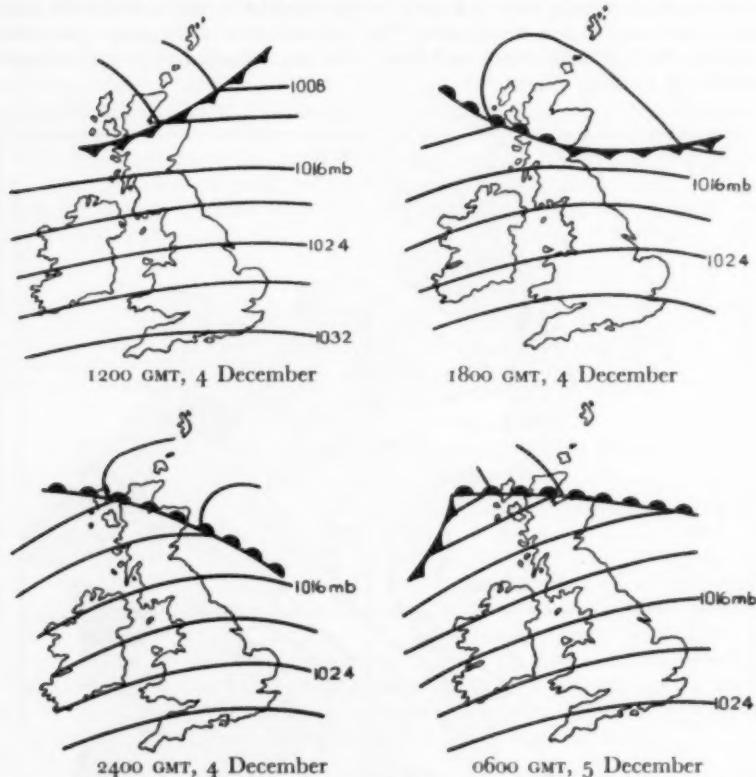


FIGURE 2—WESTERLY AIRSTREAM WITH NO FRONTS, 4-5 DECEMBER 1956

Rain fell continuously throughout the 24 hours at Prestwick Airport—more heavily at night than during the day. The rain amount was considerable. It will be seen that orographic factors appear to have played a full part in inland areas, where ratios exceed the mean. Note the markedly low value in the lee of the north Ayrshire hills.

Showery airstreams were divided into two air trajectories: between north and west and between west and south. The occasions were added together for two seasons, broadly defined as summer and winter, to counterbalance to some extent the sporadic nature of this kind of precipitation. Four comparative charts were then constructed as for single occasions.

The year yielded nine different usable synoptic situations plus the showery types. The limitations imposed by the fixed twenty-four-hour period precluded many potentially interesting cases. However, the list is quite varied as will be seen from Table I.

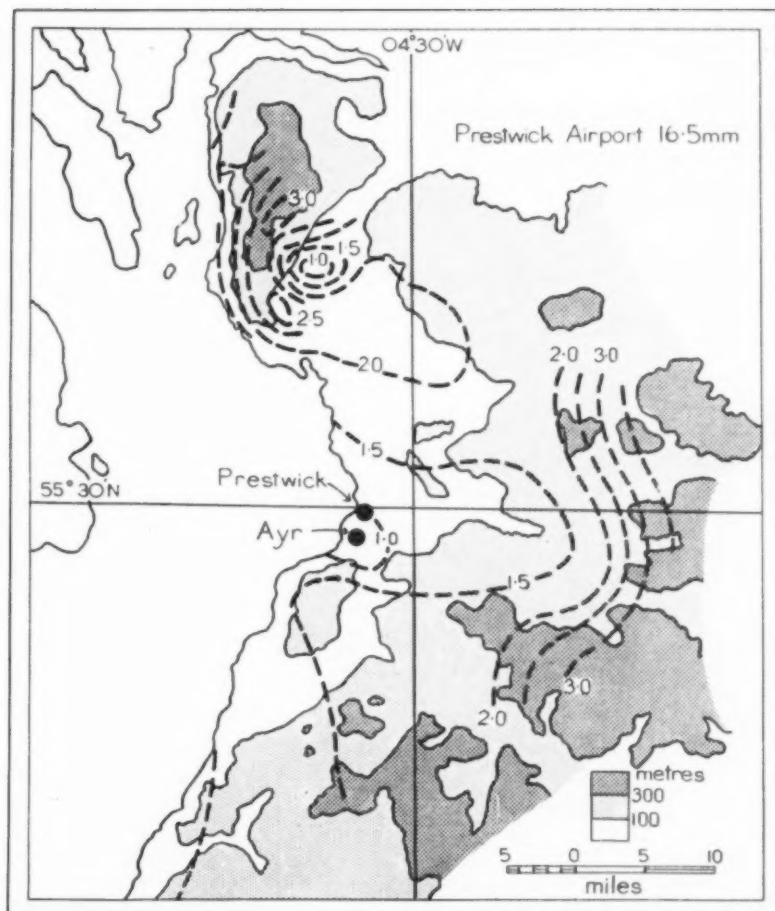
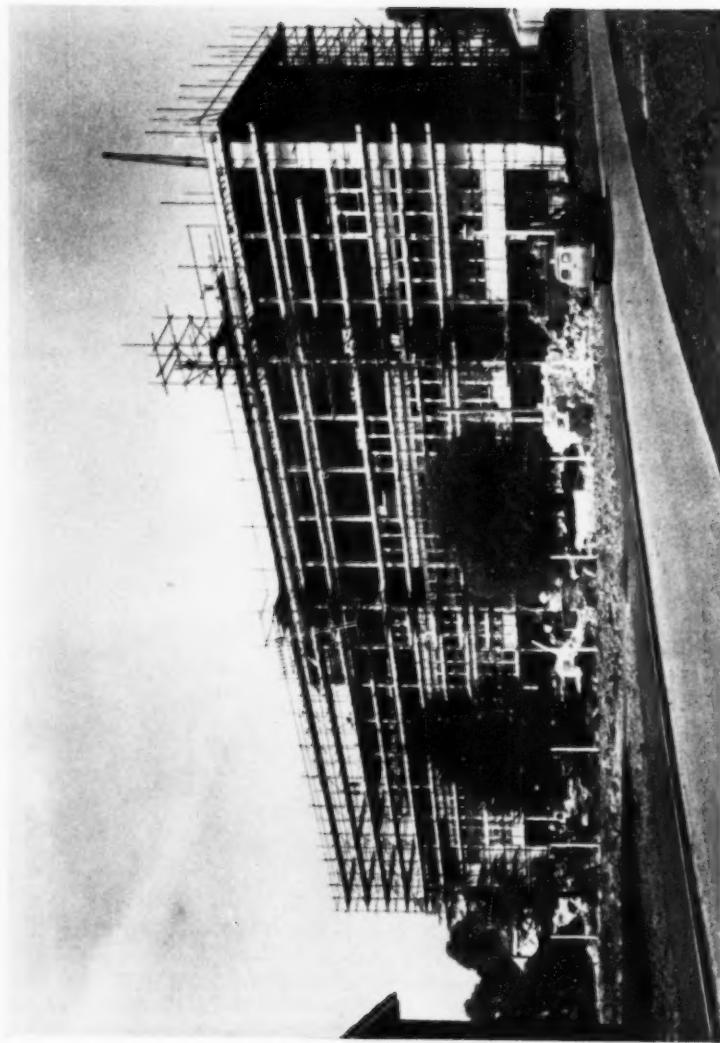


FIGURE 3—COMPARATIVE RAINFALL MAP OF AYRSHIRE, 4-5 DECEMBER 1956

To face p. 101.]



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NEW METEOROLOGICAL OFFICE HEADQUARTERS, BRACKNELL, 6 MAY 1960

TABLE I—SYNOPTIC SITUATIONS IN 1956 USED TO PREPARE RAINFALL MAPS

1. Showery type
 - Shower-stream from W-N quadrant (April-Sept., summer), 30 days.
 - Shower-stream from W-N quadrant (Oct.-March), 22 days.
 - Shower-stream from W-S quadrant (April-Sept.), 15 days.
 - Shower-stream from W-S quadrant (Oct.-March), 25 days.
2. A winter slow-moving frontal system, 26-27 Jan.
3. Warm-frontal passage with no rain behind, 4-5 Feb.
4. Passage of polar depression with associated cold frontal trough, 14-15 April.
5. Warm front moving SW-NE, 29-30 June
6. Developing wave depression moving SW-NE, 4-5 July.
7. Non-developing wave depression moving W-E, 23-24 July.
8. Frontal system moving W-E, 10-11 Aug.
9. Warm-frontal passage, 12-13 Sept.
10. Westerly airstream with no fronts, 4-5 Dec.

The final form of the compendium of maps is as follows:

- (i) Key map of stations with heights above sea level.
- (ii) Long-period mean annual rainfall map prepared from data given in *British Rainfall*.
- (iii) Set of four shower-period maps.
- (iv) Nine sets of "synoptic situation" maps, consisting of the 1200, 1800, 2400 and 0600 GMT surface charts and a note on the special features of the occasion, on one page, and, on the facing page, the ratio isopleth map.

As an illustration, Figure 1 shows the mean annual map and Figures 2 and 3 a specific occasion—a non-frontal rainy day.

In its limited way, the preparation of the charts was considered as the end rather than the means. With the relatively small amount of data available, and considering the many factors which could operate both in spatial and temporal distribution, we thought it unwise to try to deduce any empirical "rules" from the study made. Given a synoptic situation the forecaster can have recourse to the maps for a comparable type. However, some tentative points, which could be looked at as day-to-day cases occur, are:

(a) The orographic effect generally operates as would be expected from the ground contours. It is most strongly evident in the north Ayrshire hills. The relative dryness of the south coastal area appears as a feature in most synoptic occasions.

(b) In a north-westerly shower-stream the inland "raininess" is doubled in the summer compared to the winter. It is thought that this may be due to higher temperatures inland than on the coast in summer as, presumably, there is no seasonal variation in orographic lifting. This doubled raininess does not show in a west-to-south stream. Part of the reason may be that upper winds carry showers, formed over the hills to the south and south-west, northward into the low-lying areas.

(c) Although it appears only as a vague feature on the mean annual isohyets, a marked rainshadow occurred on some individual occasions on the eastern side of the hills in the north of the county. It will be noticed in the example shown as a very clear feature.

In conclusion it might be noted that, when the original work of locating the stations accurately on a base map has been done and duplicates made, the isopleth stage can be completed relatively quickly. It should, therefore, be possible to build up a good variety of synoptic occasions without using too many man-hours in the process.

REFERENCE

1. SAWYER, J. S.; Rainfall of depressions which pass eastward over or near the British Isles. *Prof. Notes met. Off, London*, 7, No. 118, 1956.

TEST OF A CRITERION FOR DETERMINING THE OCCURRENCE OF TURBULENCE AT HIGH LEVEL

By J. FINDLATER

Parker¹ has suggested that turbulence is likely to occur when:

$$u \frac{\partial^2 u}{\partial z^2} > \frac{g}{T} \left(\frac{\partial T}{\partial z} + \Gamma \right),$$

where u = component of wind in the direction of the general stream

z = height

g = acceleration due to gravity

T = absolute temperature

Γ = adiabatic lapse rate.

In order to test this hypothesis use may be made of data accumulated by the Meteorological Research Flight in a series of seventeen high-altitude flights made near Farnborough between the hours of 0800 and 1600 G.M.T. within the period 7 August 1956 to 27 January 1958. During these flights 134 flight levels were inspected for turbulence; a flight level for the purpose of this test is defined as a level at which observations were made from the aircraft of temperature, wind and turbulence. The aircraft spent at least a few minutes at each of the flight levels which were usually 1000 feet and occasionally 2000 feet apart. The lowest and highest flight levels were 20,000 feet and 46,000 feet respectively. One case of turbulence believed to be due to the aircraft crossing its own wake was not included in the analysis.

A fundamental difficulty in testing a criterion which depends upon $\partial^2 u / \partial z^2$, or even $\partial u / \partial z$, is the need for extremely accurate values of u and for detail of the structure in the vertical; besides inaccuracies of measurement the time and space variations in u give rise to an irreducible uncertainty in an adopted value at a given height. On the other hand, if values of u are smoothed over a certain height band $\partial u / \partial z$ may lose definition, and significant turning points at which $\partial^2 u / \partial z^2$ changes sign may be missed. In the tests to be described the unsmoothed values of u were used in the first place and then the analysis was repeated using smoothed values. Smoothing was carried out by plotting values of $u \pm 8 \text{ ft sec}^{-1}$ (this latter value being stated as the probable error of the aircraft winds²) and drawing a curve in which u always fell between the two extremes but contained as few maxima and minima as possible.

For day-to-day operational forecasting detailed upper wind observations made by aircraft are rarely available and it would be necessary to use data such as are provided by routine radio-sonde ascents. Accordingly the observations of turbulence were also examined for association with Parker's criterion as computed by using the values of u reported by the radar-wind observations at Crawley at the routine hour nearest to the time of the aircraft observations. As the radar-wind reports refer to a three-minute interval and to a height band of about 3500 feet, some detail is lost which may affect the value deduced for $\partial u / \partial z$. Observations at Crawley are in fact made at minute intervals and these

were also used since they can, if necessary, be made generally available. Thus the observations of turbulence have been related to Parker's criterion as determined from:

- (i) Unsmoothed aircraft winds
- (ii) Smoothed aircraft winds
- (iii) Three-minute radar winds
- (iv) One-minute radar winds.

It is questionable whether a criterion which detects turbulence but does not indicate the intensity is of much practical value. Slight turbulence does not cause much disturbance in an aircraft whereas moderate turbulence is uncomfortable and severe turbulence is a hazard. Severe turbulence was not encountered during the flights of the Meteorological Research Flight and at the 134 individual flight levels moderate turbulence was encountered only eight times and slight turbulence 40 times. In order to see whether Parker's criterion enables slight and moderate turbulence to be discriminated, the observations were analysed twice, firstly combining slight and moderate turbulence, and secondly considering slight turbulence as nil.

It would be of some value if, although the precise level at which turbulence is encountered could not be predicted, the occurrence of turbulence within a few thousand feet or so of the level could be forecast with some assurance. Accordingly the observations were also examined for occasions of turbulence within 1000, 2000 and 3000 feet of a level where Parker's criterion indicated its likelihood.

TABLE I—NUMBER OF OCCASIONS OF TURBULENCE

Derivation of u	P	at flight level			within 1000 ft			within 2000 ft			within 3000 ft		
		mod	slt	nil	mod	slt	nil	mod	slt	nil	mod	slt	nil
		number of occasions											
M.R.F. winds	>0	3	19	17	6	33	48	7	35	59	8	36	67
	<0	5	21	68	2	7	38	1	5	27	0	4	19
M.R.F. winds	>0	2	7	11	3	16	27	5	21	36	5	25	41
	<0	6	33	75	5	24	59	3	19	50	3	15	45
Crawley winds	>0	1	5	4	1	11	8	1	16	11	3	16	13
	<0	7	35	82	7	29	78	7	24	75	5	24	73
Crawley winds	>0	2	10	21	6	20	44	8	28	55	8	31	64
	<0	6	27	64	2	17	41	0	9	30	0	6	21
$P = u \frac{\partial^2 u}{\partial z^2} - \frac{g}{T} \left(\frac{\partial T}{\partial z} + r \right).$													

The basic data (number of occasions) are classified in Table I according to whether Parker's expression was positive (turbulence expected) or negative (turbulence not expected). In Table II are shown the percentage of cases when Parker's criterion was correct, and the skill score*. It may be seen from Table I that, more often than not, turbulence was not encountered at the flight level; also, more often than not, Parker's criterion was not satisfied. The coincidence of these two events leads to some rather high values of percentage correctness in Table II especially when cases of no turbulence are reinforced by regarding

* The skill score is defined³ as $(R-E)/(T-E)$ where R is the number of cases where the criterion was correct, T is the total number of cases and E is the number that would be expected to be correct by chance. This score has a value of unity if the criterion is correct in all cases and a value of zero when the number correct is equal to the number expected correct by chance.

slight turbulence as nil. In general the figures for percentage correctness indicate that Parker's criterion will give the right answer on two occasions out of three, which is slightly better than the chance result of two out of four.

TABLE II—PERCENTAGE OF OCCASIONS WHEN PARKER'S CRITERION WAS CORRECT (A), AND SKILL SCORES (B)

Position of turbulence	M.R.F. winds		M.R.F. winds		Crawley routine winds		Crawley 1-min winds		
	(a) unsmoothed	(b)	(a) smoothed	(b)	(a)	(b)	(a)	(b)	
percentage of occasions									
(A)	at flight level	68	69	63	92	66	88	59	71
	within 1000 ft	57	38	57	64	67	81	52	59
	within 2000 ft	51	29	57	55	69	75	51	36
	within 3000 ft	47	23	56	49	69	75	46	27
skill score									
(B)	at flight level	0.27	0.03	0.07	0.06	0.10	0.05	0.02	0.00
	within 1000 ft	0.21	0.02	0.08	0.01	0.18	-0.01	0.05	0.05
	within 2000 ft	0.15	0.02	0.13	0.04	0.25	-0.04	0.12	0.05
	within 3000 ft	0.11	0.02	0.13	0.02	0.26	0.06	0.09	0.03

(a) Combining slight and moderate turbulence; (b) Reckoning slight turbulence as nil.

The skill scores in the rows headed (B) indicate that as a criterion for moderate turbulence as distinct from slight turbulence, Parker's expression would not have been useful in the cases under examination. In fact the frequency distributions in Table I, if slight turbulence is regarded as nil, differ only by one from the chance distribution. The only skill scores worth noting are those which relate to the unsmoothed winds observed by aircraft at the flight levels and to the Crawley routine winds within 2000 feet or 3000 feet of the flight level. No doubt the low values for the one-minute readings from Crawley reflect the local variability of detail in the wind structure. It appears therefore that if aircraft wind observations are available, the use of Parker's criterion might help to pinpoint the levels at which slight or moderate turbulence was likely to occur. If recourse had to be made to routine radar reports of wind the level of slight or moderate turbulence may be two or three thousand feet different from that at which Parker's criterion was satisfied.

TABLE III—VALUES OF χ^2

	At flight level	Within 1000 ft	Within 2000 ft	Within 3000 ft
M.R.F. winds (unsmoothed)	8.5	8.6	χ^2
Crawley routine winds		8.2	8.9

It is interesting to note that smoothing of the aircraft winds removes detail which is significant. For the cases when the skill score exceeds 0.20, values of χ^2 have been computed.⁴ These are shown in Table III and may be compared with the value 6.63 which corresponds with the one per cent level of probability. Thus Parker's criterion appears to be significantly valid for indicating the level of slight or moderate turbulence if aircraft winds are used, and within about 2000 feet if routine radar-wind observations are used. The criterion appears to have no significance for indicating the intensity of turbulence though this negative result may be due to the comparatively few occasions of moderate turbulence.

The opportunity of evaluating the wind shear and static stability was taken to compute the corresponding Richardson number. No critical value or range of values was found which could be associated with the existence or absence of turbulence.

The most important of the parameters entering Parker's criterion is $\partial^2 u / \partial z^2$ and it is necessary to remember that it may be this parameter which contributes to the significance of the criterion for slight turbulence and that the form of a criterion involving $\partial^2 u / \partial z^2$ is not necessarily that stated by Parker.

TABLE IV—NUMBER OF OCCASIONS OF TURBULENCE AT FLIGHT LEVELS, GROUPED ACCORDING TO VALUES OF VERTICAL WIND SHEAR (M.R.F. UNSMOOTHED WINDS)

		Vertical wind shear ($\text{sec}^{-1} \times 10^{-8}$)					
		-30	-20	-10	0	+10	+20
(a)	Turbulent levels ...	...	...	4	5	11	20
	All levels ...	...	...	7	10	29	58
	Proportion of turbulent levels ...			0.57	0.50	0.38	0.34
(b)	Turbulent levels ...	...	...	1	1	2	3
	All levels ...	...	...	7	10	29	58
	Proportion of turbulent levels ...			0.14	0.10	0.07	0.05

(a) Combining slight and moderate turbulence; (b) Reckoning slight turbulence as nil.

The wind shear was calculated from the unsmoothed M.R.F. winds.

TABLE V—NUMBER OF OCCASIONS OF TURBULENCE AT FLIGHT LEVELS, GROUPED ACCORDING TO CHANGE OF VERTICAL WIND SHEAR

		Change of vertical wind shear ($\text{sec}^{-1} \times 10^{-3}$ per 1000 ft)		
		≤ -15	$-15 \text{ to } +15$	$> +15$
(a)	Turbulent levels ...	...	11	28
	All levels ...	...	25	88
	Proportion of turbulent levels ...		0.44	0.32
(b)	Turbulent levels ...	...	5	2
	All levels ...	...	25	88
	Proportion of turbulent levels ...		0.20	0.02

(a) Combining slight and moderate turbulence; (b) Reckoning slight turbulence as nil.

The amount of wind shear as calculated from the unsmoothed aircraft winds has been used to evaluate the proportion of turbulent levels, firstly combining slight and moderate turbulence and secondly considering slight turbulence as nil. These results, given in Table IV, show an increasing proportion of turbulent levels as the wind shear becomes increasingly negative. A similar tabulation, Table V, of the relation of slight and moderate turbulence to the change of wind shear with height, $\partial^2 u / \partial z^2$, shows that turbulence was relatively more frequent with negative values of $\partial^2 u / \partial z^2$. This latter result conflicts with the criterion as stated by Parker which requires positive values of $\partial^2 u / \partial z^2$ for satisfaction.

On four of the five days when moderate turbulence was encountered there was an upper ridge to the west of the flight area or an upper trough to the

TABLE VI—OCCASIONS OF MODERATE TURBULENCE

Date	Height of moderate turbulence ft	M.R.F. winds (unsmoothed)			Crawley routine winds		
		maximum deg	wind kt	level ft	maximum deg	wind kt	level ft
21.3.57	32,100	347	53	29,000	250	39*	37,500
3.4.57	41,000	276	60	38,100	320	48	45,000
14.4.58	35,800 38,800 39,600	021	74	34,800	020	79	34,000
22.4.58	25,100 27,000	285	29	29,000	270	33†	34,000
24.4.58	25,100	301	73	28,100	310	79†	29,500

* Axis of upper trough crossing area.

† Secondary maximum; primary maximum above 60,000 ft.

east, as revealed by charts of the 300-millibar level. No synoptic feature common to the five occasions could be identified. A northerly jet stream lay over Holland on 3 April 1957. The highest value of the upper winds and the levels at which these were recorded are shown in Table VI.

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3. PANOPSKY, H. A. and BRIER, G. W.; Some applications of statistics to meteorology. University Park, Pa., 1958.
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OFFICIAL PUBLICATION

The following publication has recently been issued:

GEOPHYSICAL MEMOIRS

No. 102—*Average water-vapour content of the air*. By J. K. Bannon and L. P. Steele.

Charts are presented of the average water-vapour content of the air above one square centimetre at the earth's surface and the levels 850, 700 and 500 millibars for each of the months January, April, July and October based mainly on data for 1951–55. The area covered by the charts is approximately 70°N–52°S.

REVIEWS

Sonnenstrahlung und Luftrührung (Probleme der kosmischen Physik, Bd. 31). By L. Foitzik and H. Hinzpeter. 9½ in. × 6½ in., pp. x + 309, illus., Akademische Verlagsgesellschaft, Geest und Portig K.-G., Leipzig, 1958. Price D.M.43.

This book forms Volume 31 of the established series "Probleme der Kosmischen Physik". According to the authors, F. Linke, a great personality and a leader in the investigation of solar radiation, had contemplated a book in this series before his death, and the project had been taken up by O. Hoelter who had in turn left a partial manuscript. We thus find the book appearing more than 20 years after its first being mooted. The subject is the modification of solar radiation by the cloudless (but not dust-free) atmosphere.

The treatment falls into three sections. In the first, after a brief specification of solar radiation and discussion of standard atmospheres and the distribution of ozone, water vapour and aerosol, the elements of the theory of absorption in the electronic bands of gases and of Rayleigh and Mie scattering are set out. The treatment is concise and sufficient for most meteorological purposes. Where (particularly in the discussion of Mie theory) it is limited by the space available there are ample references to fuller treatments. There follows a shorter section covering actinometry and pyrheliometry, that is, the measurement of the radiation received directly from the sun, and the determination of the solar constant. The Smithsonian method of solar constant determination is set out carefully and there are two most interesting tables of values of this constant published between 1837 and 1955. Recent work in America by Stair, Johnson and others does not have the attention it deserves.

The remainder of the book is devoted to the methods and results of investigating atmospheric transmission. It comprises two chapters, one of which is devoted to the question of the various measures of turbidity, which have given rise to a large literature in the German language but have been little used elsewhere. They were never soundly based in theory, and with the increasing availability of spectroscopic methods seem to have outlived their usefulness. One feels that the authors may hold this view—they treat the subject rather formally, as though in duty bound, and provide the necessary tables and nomograms for practical use, but pass without undue discussion of results to a consideration of various modern investigations of ozone, water and dust in the atmosphere. This includes a brief survey of ozone investigations with the Dobson spectrophotometer, and of Volz's measurements on scattering by dust. The book closes with a mention, but no detail, of the theoretical work of Chandrasekhar and Sekera. English readers will find it useful in two ways—as a guide to a voluminous literature now of mainly historic interest, and as an introduction to the modern standpoint; they will not find a similar text in their own language.

The book is very well produced, but proof reading has been neglected—there are many minor misprints, particularly in proper names.

G. D. ROBINSON

Turbulent transfer in the lower atmosphere, by C. H. B. Priestley. 8½ in. × 5½ in., pp. vii + 130, illus., University of Chicago Press, U.S.A. (agents: Cambridge University Press, London), 1959. Price: 28s.

When Sir Graham Sutton's *Micrometeorology* was published in 1953 a basic textbook was provided on a subject which, in the words of the review written in this magazine, had previously held for many meteorologists some of the characteristics of a "closed shop". It would also have been true to say at the time that foundations had by then been laid from which it was clear that further significant advances could soon be expected, for the composition of *Micrometeorology* was begun at a stage when increasing time and opportunity was just being found to turn to those much needed observational studies of eddy structure and transport in the lower atmosphere, which had been advocated before 1939, especially by P. A. Sheppard in this country, and then perforce set aside. The recent development of this aspect of the subject forms one of the main themes of the short book which has been written by Dr. C. H. B. Priestley as a timely

supplement to the earlier work. The event is singularly appropriate in view of his early association with the "Sutton school", and in view of the acknowledged leading contributions which he and his colleagues in Australia have made to the subject in the last ten years.

The book is an embodiment and extension of a series of lectures on the work of his group, given by Dr. Priestley at the University of Chicago in 1957. Following a short introduction the main chapters are: 2. The eddy flux and its measurement; 3. The shearing stress and the wind profile; 4. Heat convection and the temperature profile; 5. The spectrum of turbulence and the structure of free convection; 6. Theories of buoyant motion; 7. Evaporation; 8. Evolutionary aspects of energy transfer. As is evident from their titles five of these deal with the measurement and understanding of eddy structure and of the fluxes of momentum, heat and water vapour. Chapters 4 and 6 and the latter part of Chapter 5 represent another main theme, one on which Priestley has been personally engaged, namely the problems of free convection as distinct from mechanical turbulence. The emergence here of an attractively coherent picture of various aspects of convection in the lower atmosphere is a welcome development. Finally, if there are still suspicions of a "closed shop" atmosphere in micrometeorology, these should be dispelled by the short but highly interesting discussion of the role of vertical heat flux through the atmosphere and the ground in the processes of diurnal variation and air-mass adjustment of temperature. A substantial part of this consists of Priestley's own recent contribution, otherwise available, but not easily so, as a university contract report.

In attempting an analysis and integration of the development of a subject so closely up-to-date, contentious issues are never completely avoidable, and there may be some on which not all the leading workers in the field yet see eye to eye. All the more so then is it inconceivable that anyone seriously involved in this field could fail to find this account consistently informative and stimulating. The book is concisely written, well produced, and well worth the price.

F. PASQUILL

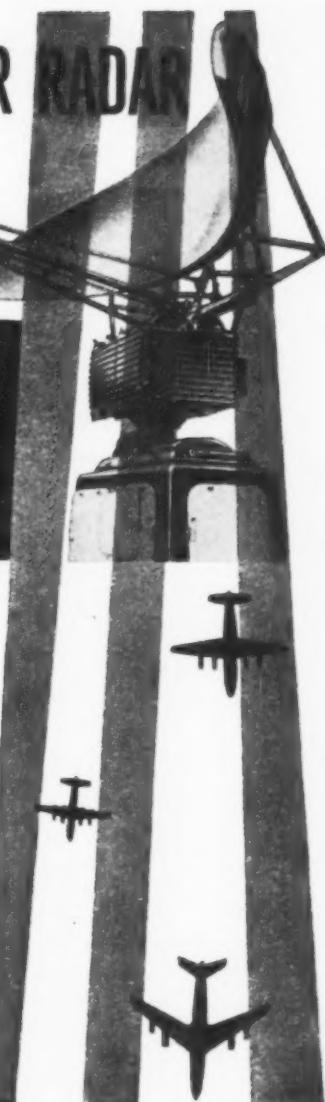
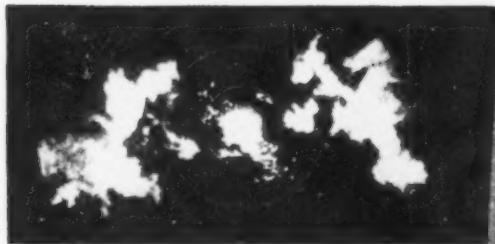
METEOROLOGICAL OFFICE NEWS

Retirement.—The Director-General records his appreciation of the services of:

Mr. F. H. Dight, Principal Scientific Officer, who retired on 31 May 1960. He joined the Office in May 1925 as a Junior Professional Assistant in the Forecast Division at Headquarters where he remained, apart from a short spell in the General Climatology Division, for nine years. In 1934 he was transferred to an aviation outstation, but a year later he returned to the Forecast Division and remained there for a further eight years. In 1943 he was again transferred to an aviation outstation, and subsequently served at a number of such stations. From 1950 until his retirement he was the Chief Meteorological Officer at Headquarters, Royal Air Force Coastal Command. During the First World War he served in the Royal Air Force from 1917-19. Mr. Dight has accepted a temporary appointment in the Meteorological Office.

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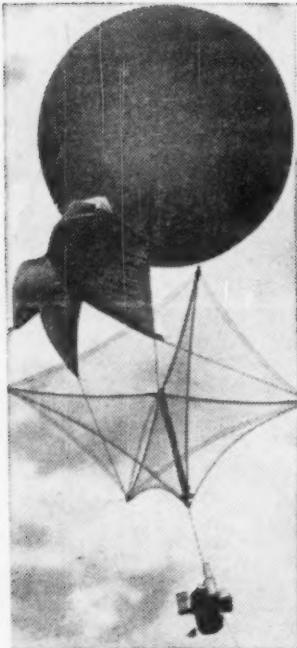
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